Aggregation of Type Curves
The Good, The Bad & The Ugly

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Outline

- Background on Aggregation Principles
- The Good - Increased Reserves, easier to meet economics threshold in challenging times
- The Bad - Using aggregation for Resources other than Reserves
- The Ugly - Making business decisions based on limited well counts – insights from aggregation principles
- Conclusions

Aggregation Principles 101

- Roll a 10 sided die. The Probability of rolling a 1 is 10%. Realizing an outcome that exceeds 1 90% of the time. We are reasonably certain we will roll a 2 or more 90% of the time.

- Lets review the rolling of a series of die to get insights into aggregation

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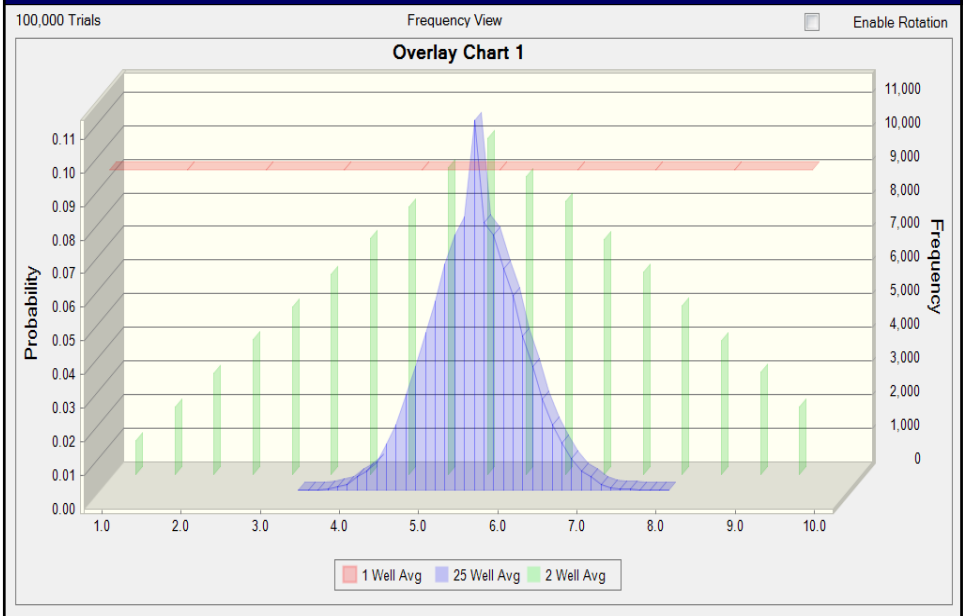
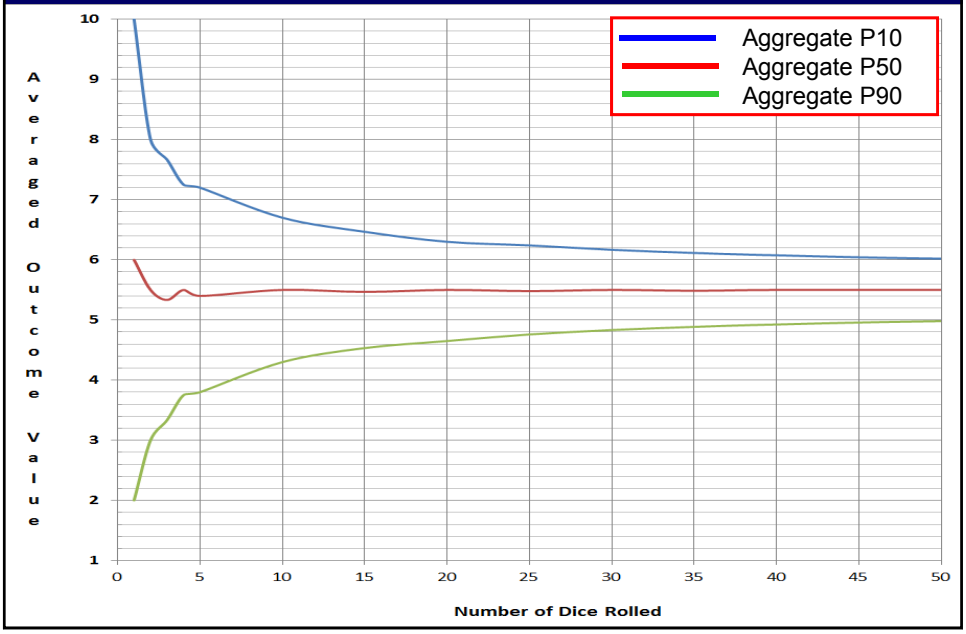
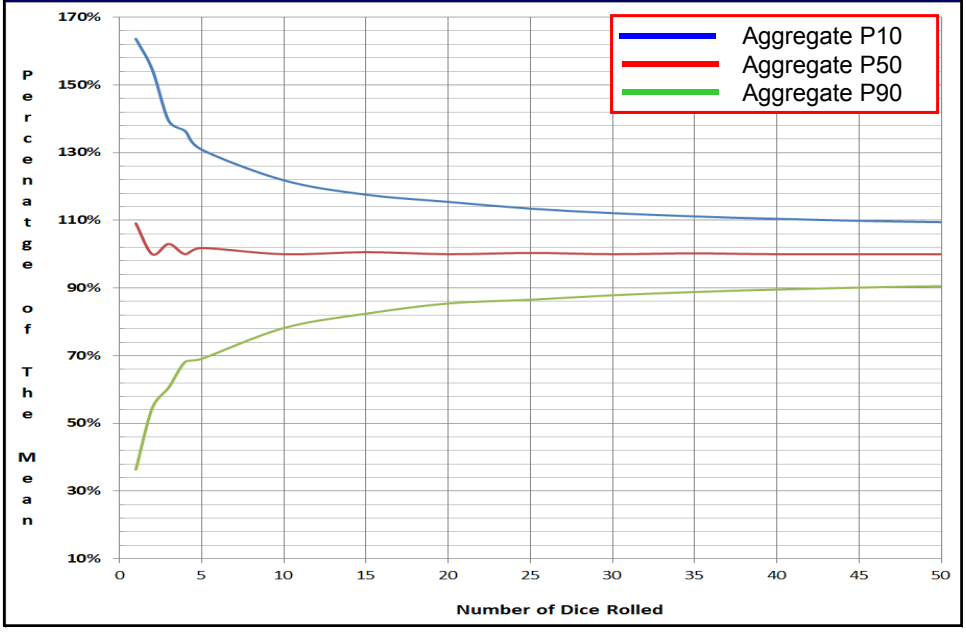
With Increasing Dice Rolls The Variance Decreases



Trumpet Charts Reveal How The Variance Decreases With Increasing Dice Rolls



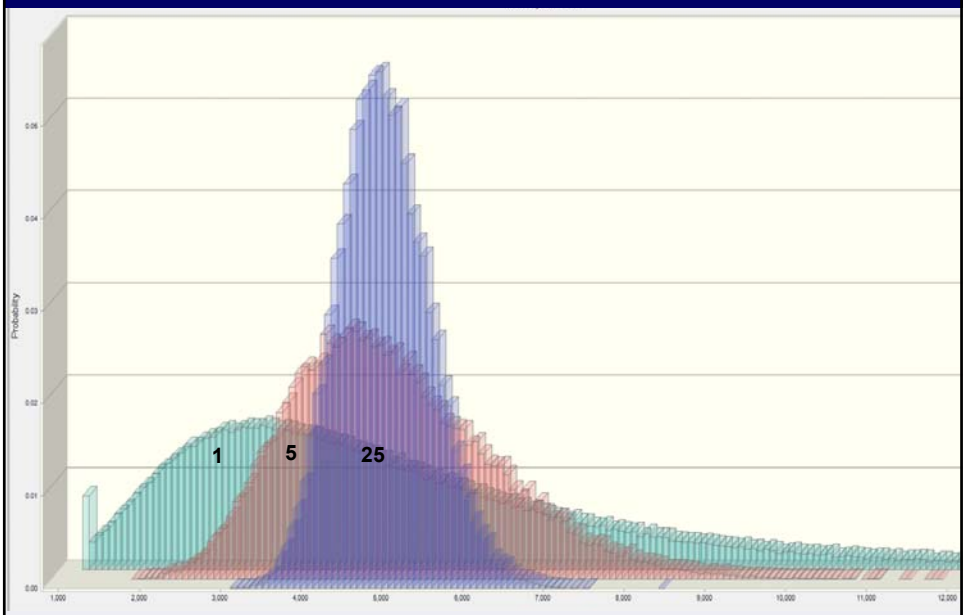
In This Trumpet Chart The Outcomes Are Normalized as Function of The Mean



Trumpet Charts For EUR Type Curves

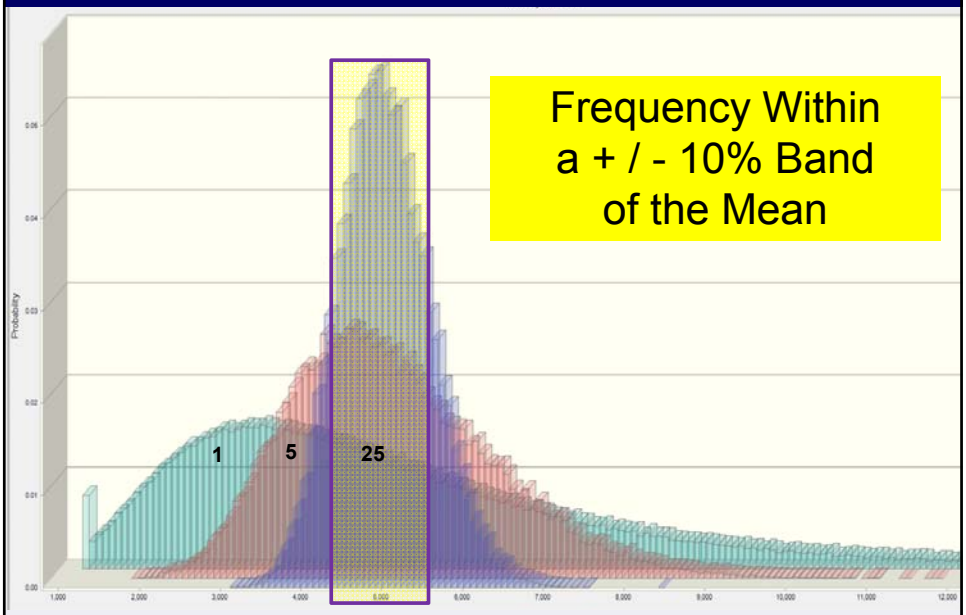
- Next we will apply the principles of Aggregation to EUR Type curves.
- Reserves are based on a multiplicative process and are therefore well represented by lognormal distributions.
- We avoid the lognormal pdf's near zero values and values approaching infinity, by sampling with replacement at values below a high side limit and above a low side limit. Often called "spiking" the distribution.

Aggregating EUR Type Curve With a P10/P90 Ratio of 4



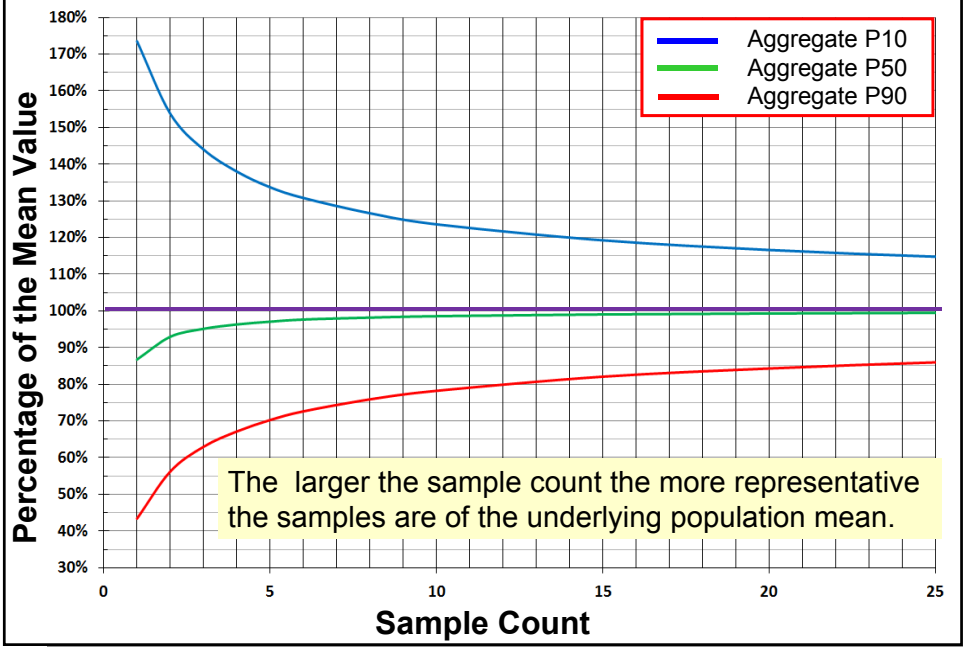
Impact of the Aggregation on a 5 & 25 well program

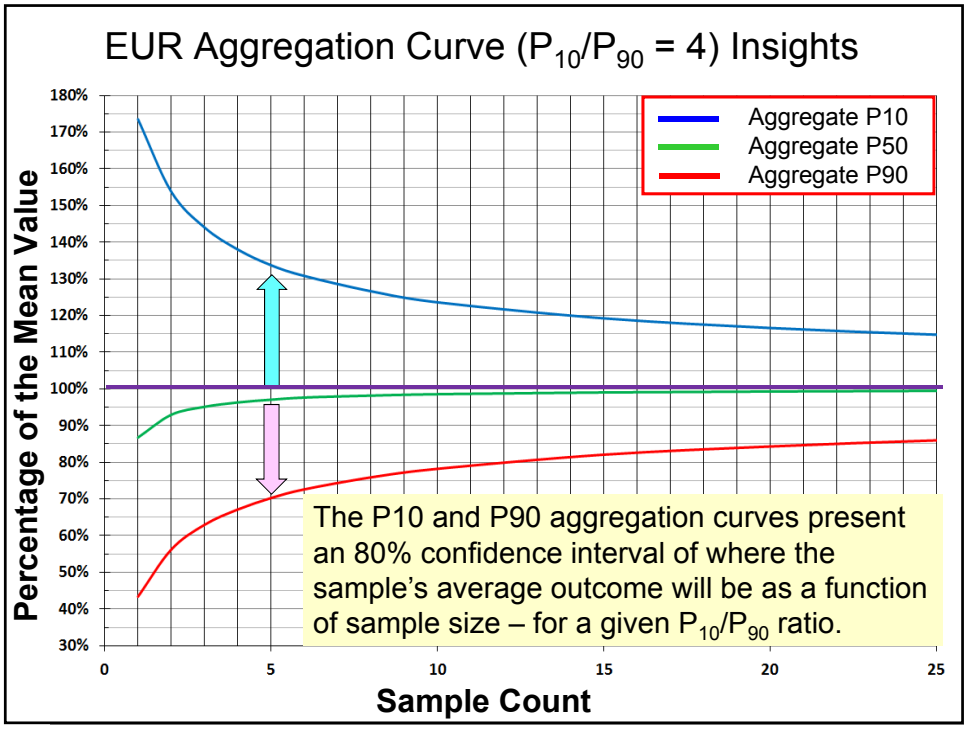
Aggregating EUR Type Curve With a P10/P90 Ratio of 4

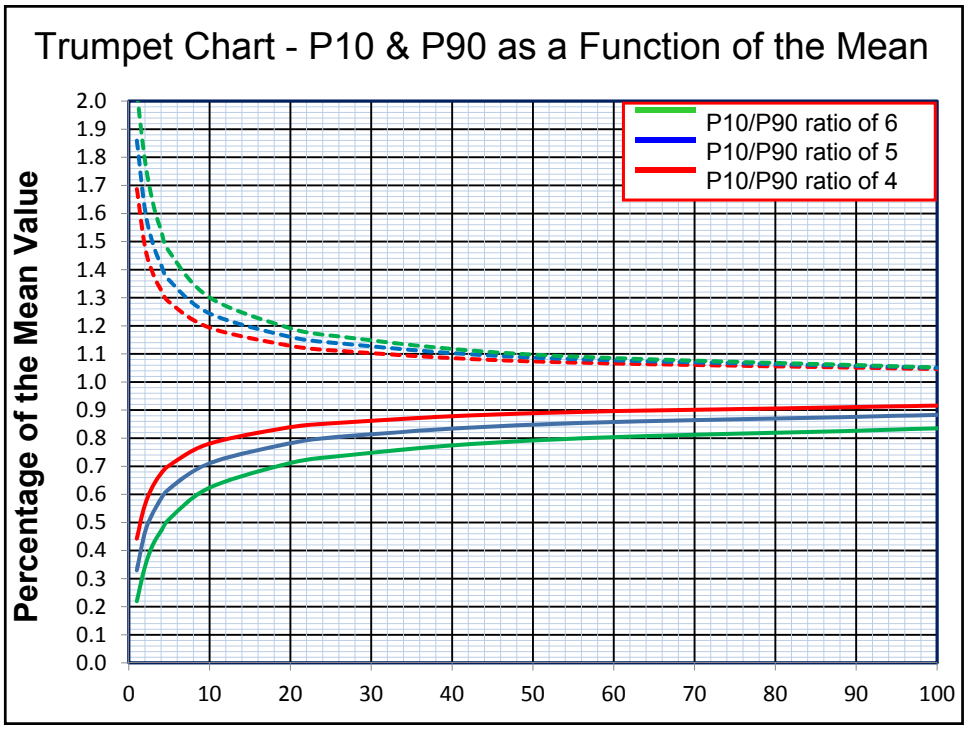


Impact of the Aggregation on a 5 & 25 well program

EUR Aggregation Curve (P_{10}/P_{90} = 4) Insights




EUR Aggregation Curve (P_{10}/P_{90} = 4) Insights
Aggregate P10
Aggregate P50
Aggregate P90
Percentage of the Mean Value
180%
170%
160%
150%
140%
130%
120%
110%
100%
90%
80%
70%
60%
50%
40%
30%
0
5
10
15
20
25
Sample Count
The P10 and P90 aggregation curves present an 80% confidence interval of where the sample's average outcome will be as a function of sample size – for a given P_{10}/P_{90} ratio.


Trumpet Chart - P10 & P90 as a Function of the Mean
P10/P90 ratio of 6
P10/P90 ratio of 5
P10/P90 ratio of 4
Percentage of the Mean Value
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
70
80
90
100

Aggregation of Reserve Methods

- The best methodology is Monte Carlo aggregation.
- The graphs published in SPEE Monograph 3 are an excellent approximation method. They assume perfect information and a common net interest.
- When Net Interests vary use the derived aggregation factor multiplied by the well net interest (as described in SPE 159174).

Monograph 3 Author's Definition of EUR

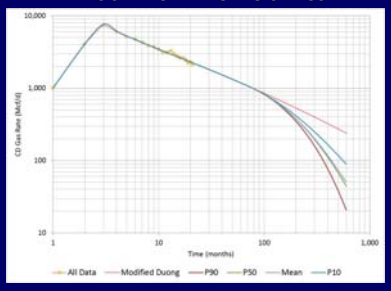
- EUR should be thought of as the distribution of your "technically recoverable reserves at a specified set of economic conditions.
- This is where the differences begin.
  - For SEC reserves fixed, pricing, differentials, capital and operating expenses are the norm.
  - For COGEH & PRMS these values can be forecasted but they must be disclosed. Hence Operators may see differences for the same asset.
  - For internal decision making the EUR should be based on your firm's internal price, inflation, differentials, capital and operating forecasts. In the majority of cases this will not be the SEC values!

Probabilistic EUR Forecasting

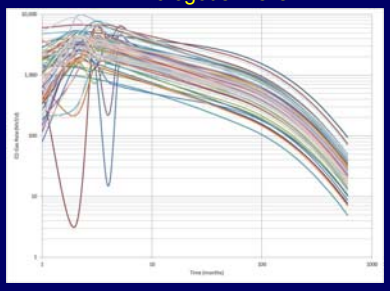
- Probabilistic forecasting supports using distributions for the uncertain variables such as:
  - The initial Arps 'b' and Di factors
  - Time to boundary dominated flow (BDF)
  - An Arps 'b' under 1 after BDF, e.g. transitioning to an Exponential Dmin approach after BDF.
  - The impact of compaction
  - The impact of desorption
- From this probabilistic approach we can derive the per well P50 which should be thought of as our per well "Best Technical Estimate".
- Aggregation allows us to determine a Project's P50 which should be thought of as our "Best Technical Estimate" of the Project.

Building Probabilistic Production Type Curves

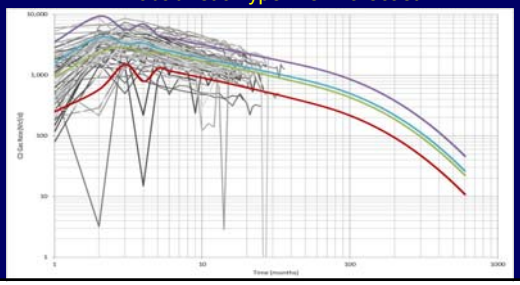
Each Well – Derive a Mean



All Analogous Wells



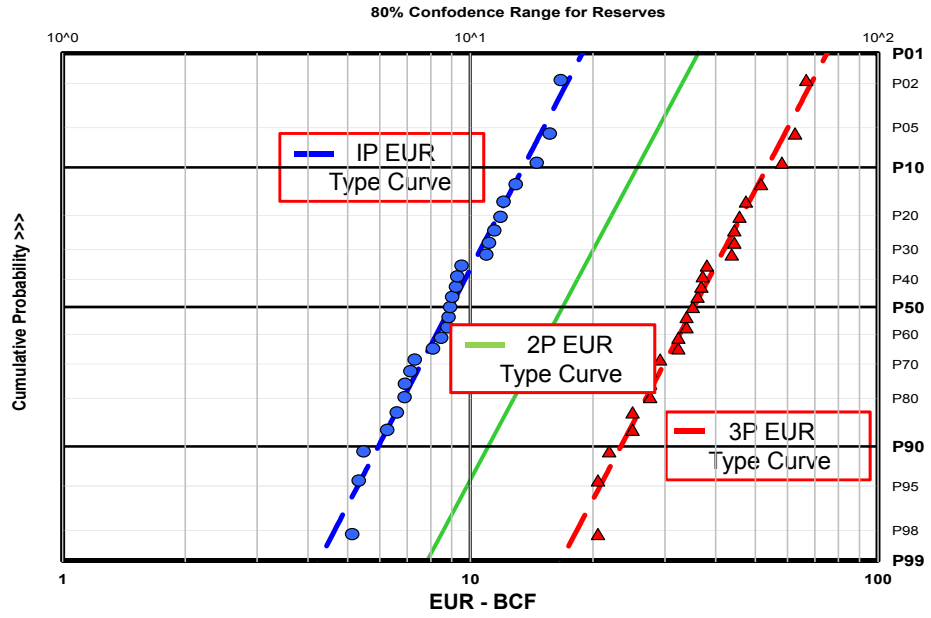
Probabilistic Type Well Forecast



Which EUR to Use For Aggregation

- PRMS, the SEC and COGEH allow aggregation to the Project level. Determining the economic viability of a project is based on this level of aggregation to our P50 or best technical estimate.
- The SEC, PRMS and COGEH do not allow aggregation beyond the Field or Property level.
- Based on the above we infer that a Project cannot exceed the limits of the Property or Field boundary, for aggregation of reserves.
- ROTR requires that Resources be aggregated by categories, of 1P, 2P and 3P. ROTR acknowledges what we intuitively know,
  - that our limited samples are not truly representative.
- ROTR guidelines recognize that aggregation based on limited data sets is flawed unless the irreducible uncertainty based on the sample size is acknowledged.

ROTR Recommendations for Aggregation



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Present Value vs EUR Insights

Assumptions:

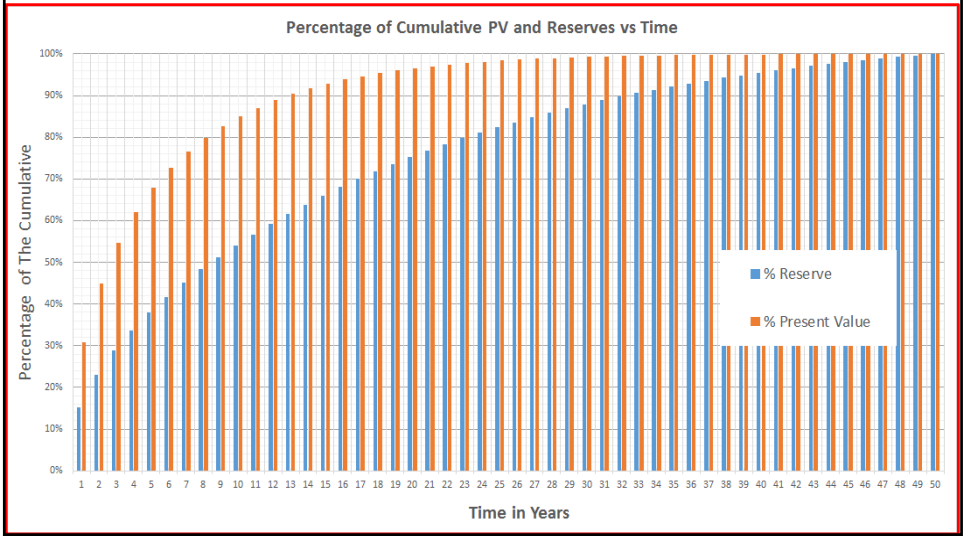
- 3,000 m lateral with 36 fracture stimulation stages
- IP 60 production rate has a P90 of 7,500 MCFD and a P10 of 30,000 MCFD. A ratio of 4.
- Arps "b" ranges from 1.6 to 2.0
- Dmin varies from 5% to 15%
- Di varies from 50 to 70%

Recommendations:

- For Corporate evaluations base Portfolio funding decisions on the mean
- For team metrics base accountabilities on the aggregated Portfolio P50
- In Resource plays, Corporate decision making should not be connected to your reserve bookings.

Present Value vs EUR Insights

From an economic perspective 80% of the value is associated with the first 8 years of production with less than 50% of the EUR produced. The next 42 years of production delivers 20% of the PV and just over 50% of the EUR.



Which EUR to Use For Aggregation?

- After 12 years of production we realize 90% of the value of the reserves.
- As an industry we have enough production history in shale and tight reservoirs to have in excess of 90% confidence in our ability to use the modified Arps, Yu modified SEPD or modified Duong to forecast our production and hence reserves out to 12 years or 60% of the reserves.
- Based on this our 2P EUR Type curve should be relied upon to be a slightly conservative value of most resource plays.
- In plays where compaction, liquid drop-out etc are not an issue a strong argument can be made for using the mean EUR.
- Where Adsorption is expected to be significant, type curve generated EURs may be on the conservative side.

Present Value vs EUR Insights

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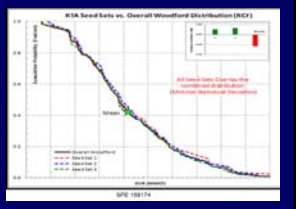
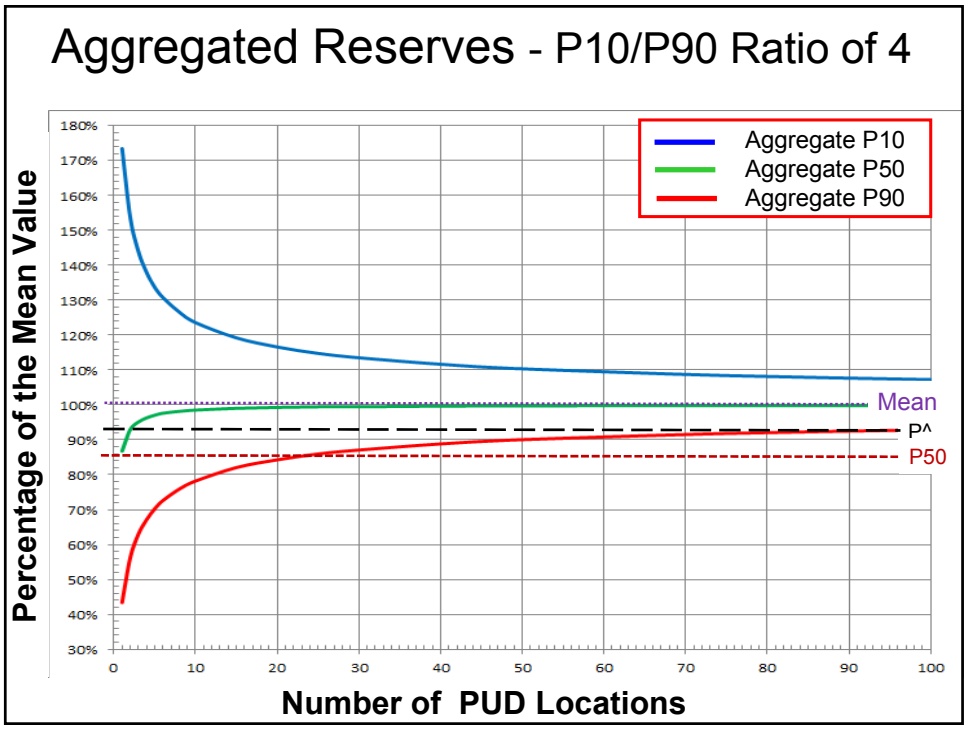
SPEE Monograph 3 PUD Aggregation

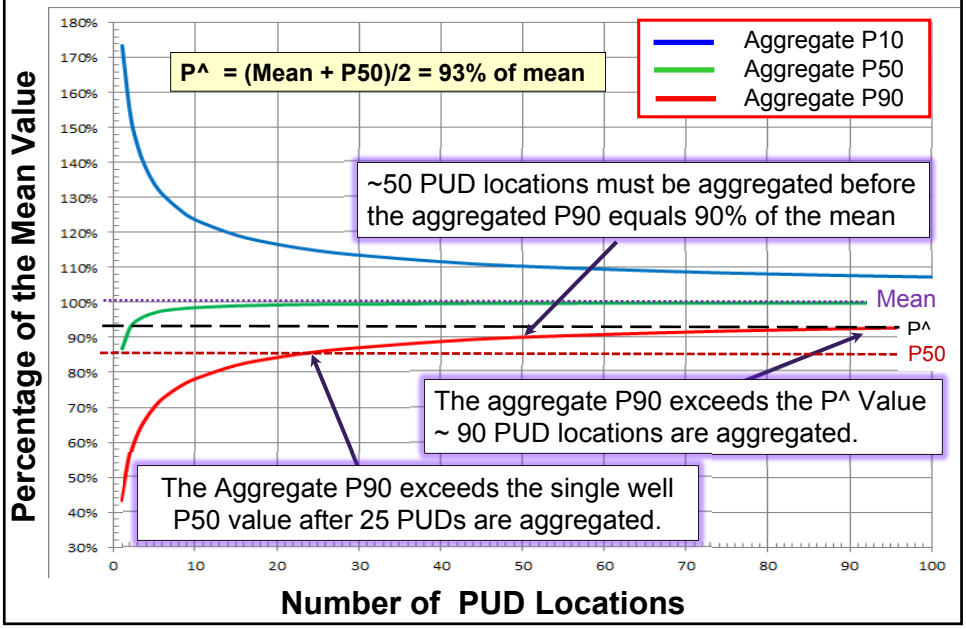
- Monograph 3 uses EUR.
- In SPE 159174, EUR was interpreted as per the ROTR guidelines.
- The 1P for each well was plotted to derive a 1P EUR Type Curve.



- While this approach is warranted for limited data sets (the typical ROTR scenario). With hundreds of wells, as required to by Monograph 3, when PUDs exceed 100 locations aggregation to the mean EUR less 10% or more is warranted.
- If P^ was used then the aggregated PUD reserve level should not exceed P^ EUR less ten percent or more.
- Simply put if you validate the mean EUR less 10% or more that should be your limiting factor in aggregation.



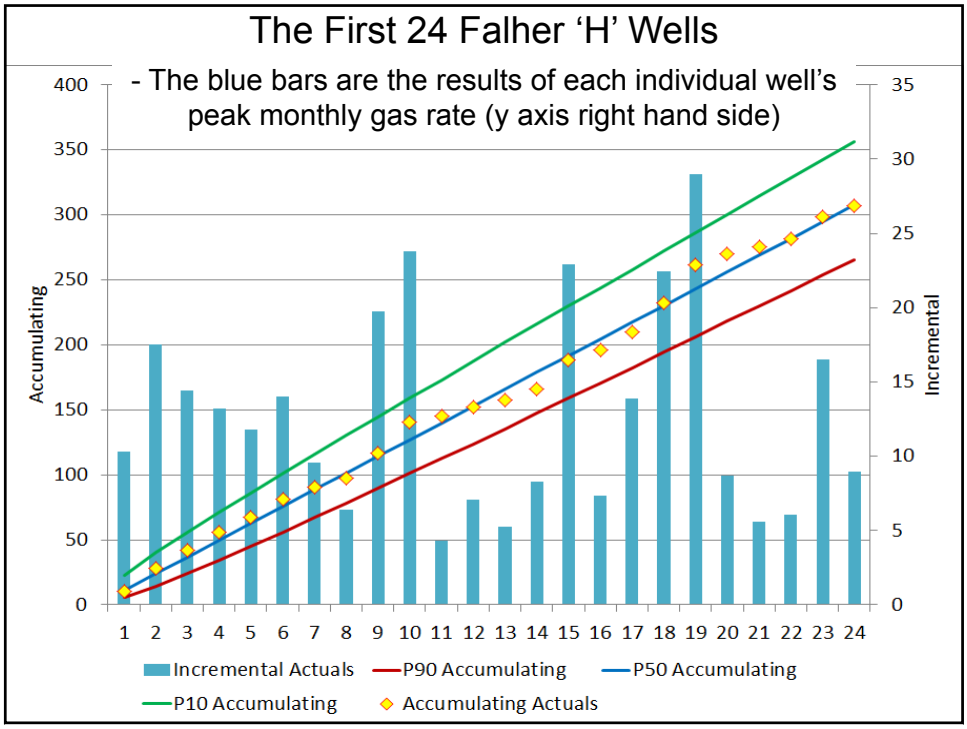
Aggregated Reserves - P10/P90 Ratio of 4

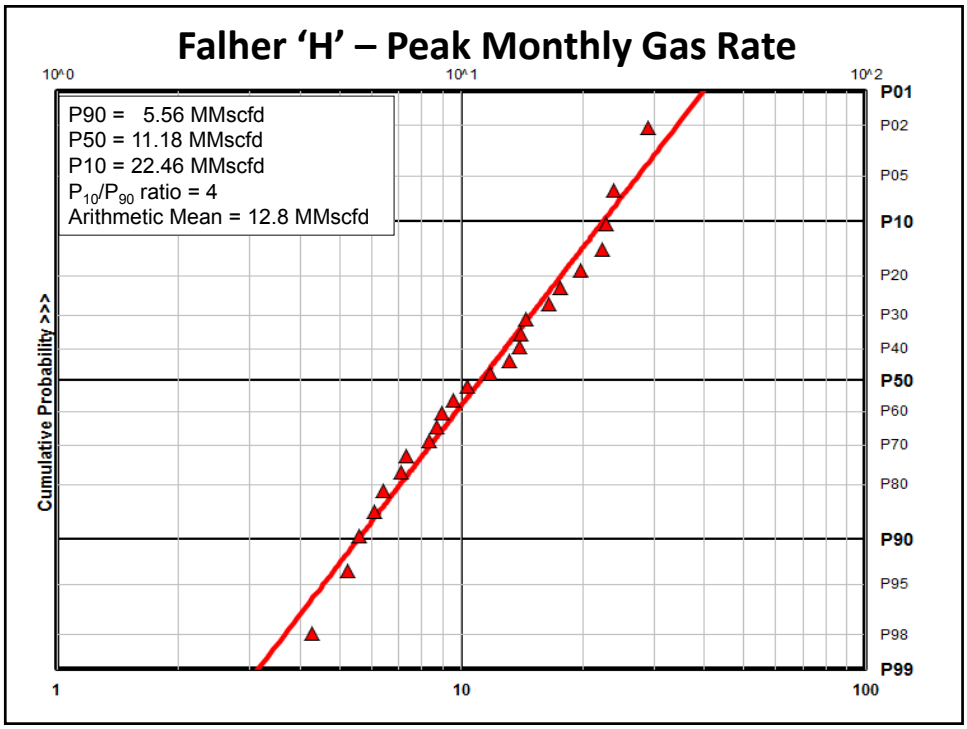


Application of Aggregation Curves – The Ugly

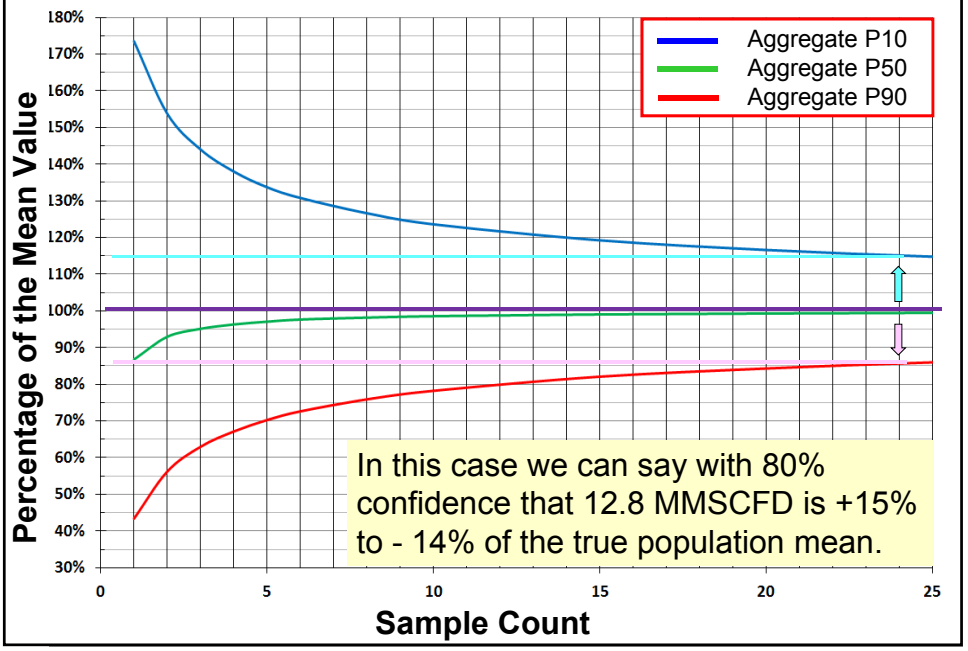
Our industry has done a poor job of acknowledging the uncertainty that exists in limited data sets. Hence the need for ROTR guideline of separate 1P. 2P and 3P type curves.

Let's look at an example based on the Falher "H' Pool in Alberta to see how limited data sets should be evaluated from a "Business Decision", perspective.


The First 24 Falher 'H' Wells
- The blue bars are the results of each individual well's peak monthly gas rate (y axis right hand side)
Accumulating
Incremental
0
50
100
150
200
250
300
350
400
0
5
10
15
20
25
30
35
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Incremental Actuals
P90 Accumulating
P50 Accumulating
P10 Accumulating
Accumulating Actuals


Falher 'H' – Peak Monthly Gas Rate
10^0
10^1
10^2
P90 = 5.56 MMscfd
P50 = 11.18 MMscfd
P10 = 22.46 MMscfd
P10/P90 ratio = 4
Arithmetic Mean = 12.8 MMscfd
Cumulative Probability >>>
P01
P02
P05
P10
P20
P30
P40
P50
P60
P70
P80
P90
P95
P98
P99
1
10
100

Falher ‘H’ Aggregation Insights



Application of Aggregation Curves – The Ugly

You are now drilling next year’s 10 horizontal well program.

What is your 80% confidence range of the 10 well Program’s per well average outcome?

Application of Aggregation Curves – The Ugly

- We have established that we are 80% confident that the "population mean" is between 11 to 14.7 MMSCFD.
- Think of the term "population mean" as the arithmetic average of a 200 well program.

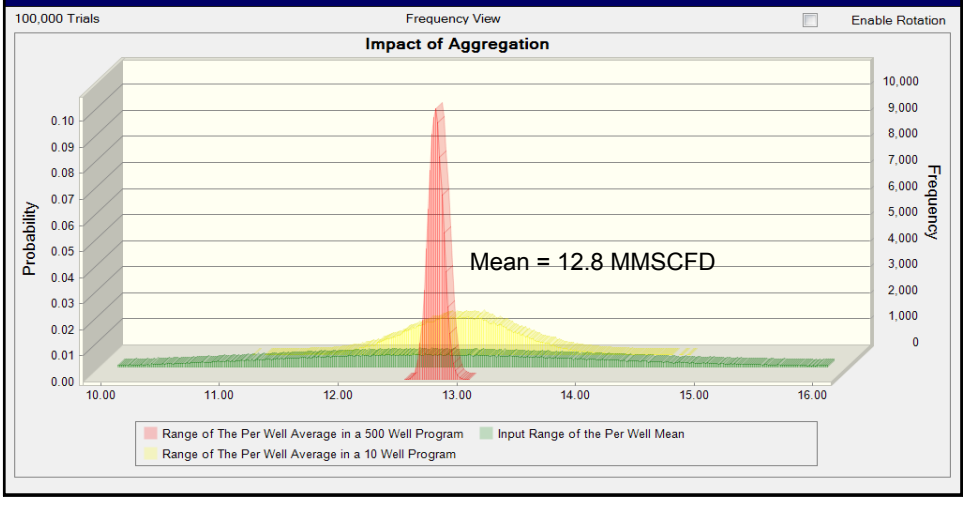
So what can we expect with an 80% confidence interval from next year's ten well program?

The caveats are that:

- Drilling and completion technique will be analogous
- We are reasonably certain that the Geology is analogous

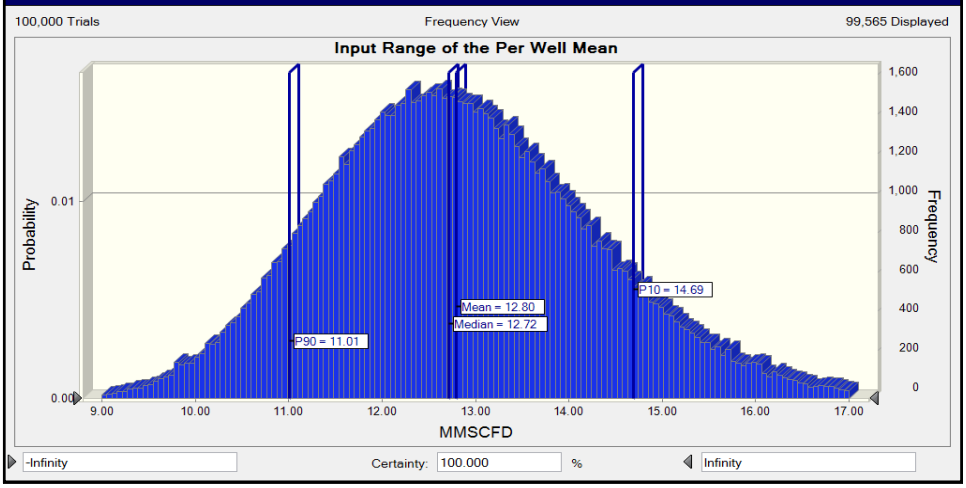
Application of Aggregation Curves – The Ugly

- Simple aggregation will always converge on the mean value
- Simple aggregation is incorrect as it does not honour the irreducible uncertainty based on the original 24 well sample set



Application of Aggregation Curves – The Ugly

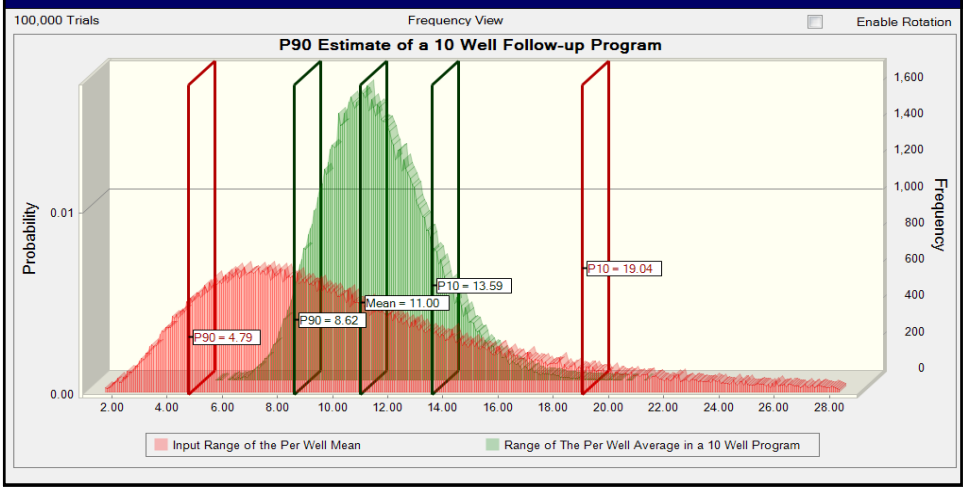
- Today we are 80% confident that the average well rate for a 200 well program will be between a P90 of 11 and a P10 of 14.7 MMSCFD.
- To understand what may occur in next year's ten well program, we'll evaluate the P90 and P10 outcome of the mean scenarios .



Application of Aggregation Curves – The Ugly

P90 Scenario:

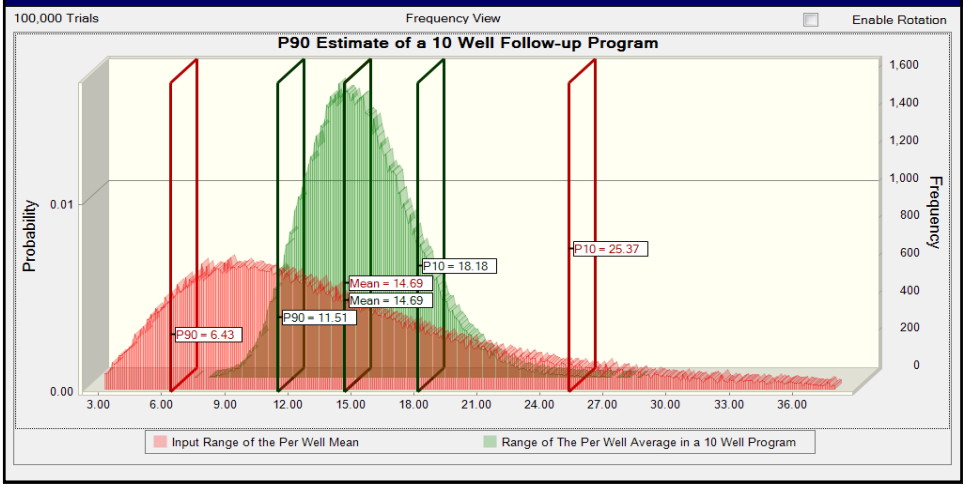
- They may average as low as 8.6 MMSCFD, as the population mean could be as low as 11 MMSCFD.



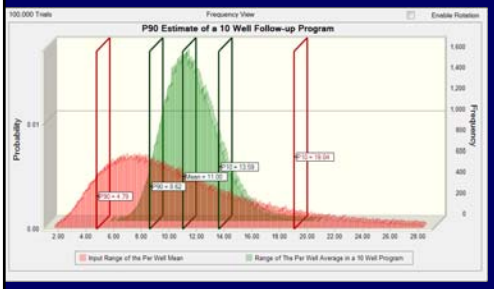
Application of Aggregation Curves – The Ugly

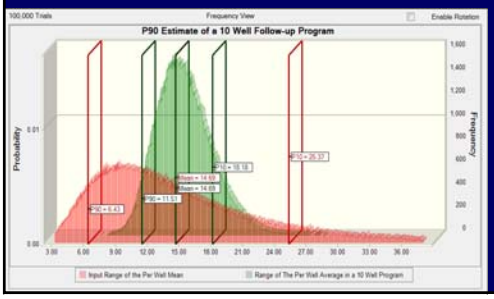
P10 Scenario:

- They may average as high as 18.18 MMSCFD as the population mean may be as high as 14.7MMSCFD

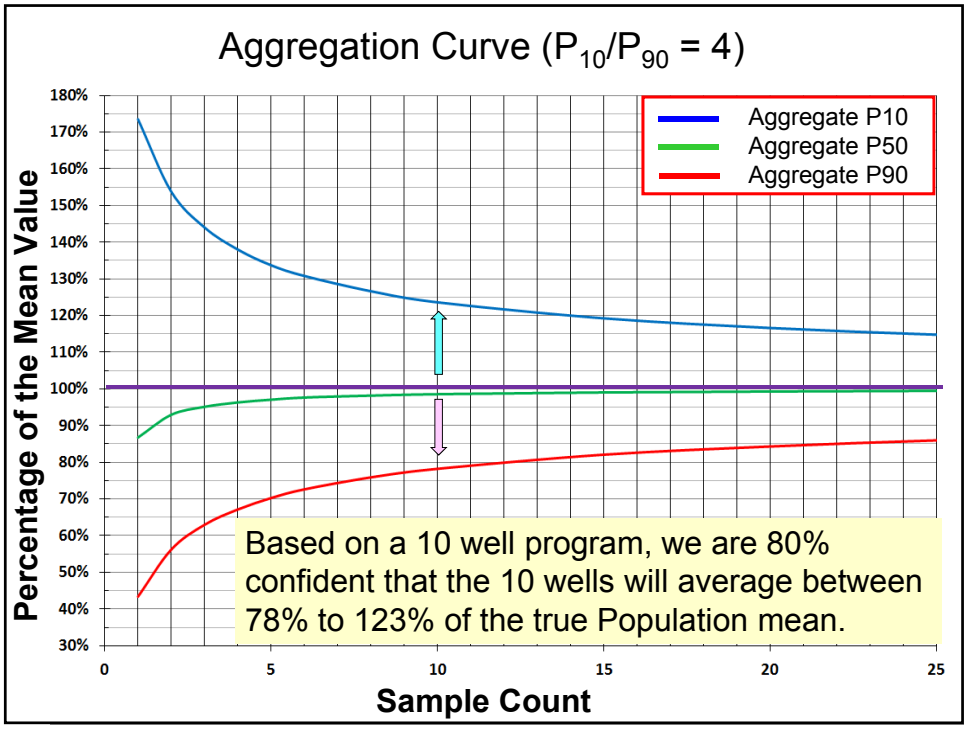


Application of Aggregation Curves – The Ugly





- By combining the P90 low and P10 high side scenarios, we can state with 80% confidence that the average of the next 10 wells will be between 8.62 and 18.18 MMSCFD.



Application of Aggregation Curves – The Ugly

- We have established that we are 80% confident that the true population mean is between 11 to 14.7 MMSCFD.
- Based on a P90 scenario "true population mean" of 11 MMSCFD, a 10 well sample based on a P10/P90 ratio of 4, would average 8.6 MMSCFD or more 80% of the time.
- In the P10 scenario for the "true population mean" of 14.7 MMSCFD, a 10 well sample based on a P10/P90 ratio of 4, would average 18.2 MMSCFD or more 10% of the time.
- Our best technical estimate would be 12.5 MMSCFD. 50% of the time we would expect to average 12.5 MMSCFD or less and 50% of the time we would average 12.5 MMSCFD or more. On average we would expect 12.8 MMSCFD.

Conclusions

- The next time you observe variance in a program do not immediately assume that things are changing!
- In resource plays follow the ROTR guidelines until there is adequate production history and well counts.
- Base portfolio funding decisions on the mean.
- For booking of PUDs use the aggregated portfolio P50 as your "Best Estimate" in your economic evaluations.
- For well counts below the SPEE Monograph 3 guidelines assess the uncertainty in the mean value of your data.
- Reverse engineer breakeven parameters to provide management with guidance on the robustness of their funding decisions.

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